Comparison of Lipid Content and Fatty Acid Composition and Their Distribution within Seeds of 5 Small Grain Species

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Abstract: Barley, oats, rice, sorghum, and wheat, each with two genotypes, were sequentially abraded by an electric seed scarifier. The pearling fines (PF) and pearled kernels (PK) at each cycle were analyzed for lipid (mostly nonpolar) content and fatty acid (FA) composition. The oil content in whole or dehulled grains ranged from 2.18% of a wheat variety to 6.38% of an oat line. Compared with barley and wheat, rice, oat, and sorghum had higher relative % of C18:1 (31.60 to 36.64 compared with 12.15 to 15.61) and lower % of C18:2 (35.69 to 45.44 compared with 50.79 to 61.50). The relationship between oil content in PF and the cumulative level of surface removal essentially describes the distribution pattern of oil content within a seed. Barley, rice, and sorghum had a similar distribution pattern, characterized by a rapid rate of decreasing for the first few outer layers and then by gradual decrease to a flat value toward the inner core. In contrast, distribution within oats was characterized by a gradual reduction in oil content across the seed. The distribution of oil within wheat fell between the former 2 types. For all 10 grains, from seed surface to inner core, C16:0 and C18:0 increased, C18:1 and C18:3 decreased, and C18:2 changed slightly, providing a new reason for improved oxidative stability for pearled kernels. The differences in the changing intensity of FA composition among grain species correspond to those in oil distribution within a seed, while varietal difference in distribution patterns of content and FA composition of lipids within a species was insignificant.

Keywords: distribution, fatty acid, grains, oil content, pearling

Practical Application: This study was the first to document fatty acid distribution across a grain seed. Results provide 2 major reasons for improved oxidative stability of pearled grains: reduced oil content and shift of fatty acids toward more saturated and less unsaturated composition.

Introduction

For the majority of the world population, cereal-based foods constitute the most important source of energy and nutrients. Cereal grains are generally divided into several structural parts, including hulls, pericarp, testa, embryo (germ), aleurone, and endosperm. These structural parts vary in composition, nutritive values, and end uses. This feature dictates heterogeneous distribution of nutrients throughout a seed. Several processing methods, such as roll milling, de-germinating, and pearling, have been used to remove germ and/or outer layers of cereal grains. The processes reduce undesirable components, such as phytate (Liu and others 2007), while improve certain characteristics of remaining kernels, such as appearance, texture, cooking quality, oxidative stability, and digestibility (Klamczynski and others 1998, Yeung and Vasanthan 2001). Equally important is that germ and bran fractions removed from grains generally have increased end-use values due to concentration of many beneficial nutrients, such as lipids, protein, vitamins, minerals, and nutraceuticals (Summer and others 1985; Lampi and others 2004; Liu and Moreau 2008). This has led to commercial production of corn germ oil, rice bran oil, and wheat germ oil.

Compared to starch and protein, the content of lipids in most cereals is relatively low (about 3%). Their contribution toward the nutritional value as well as storage stability of cereal-based food or feed, however, is important. Therefore, various studies have been carried out to document the content and fatty acid (FA) composition of lipids in whole grains (Welch 1975; Price and Parsons 1975; Zhou and others 1998; Osman and others 2000; Mehmood and others 2008) as well as in several structural parts (Youngs and others 1977; Price and Parsons, 1979; Hargin and Morrison 1980; Bradbury and Collins 1982; Banas and others 2007) from grains of different species and varieties. However, research on distribution of lipid content across a cereal seed has been limited (Liu and Moreau 2008), while none has reported on distribution of FA composition within a cereal grain.

In this study, 5 small grain species, each with 2 genotypes (varieties or breeding lines), were sequentially pearled. The pearling fines (PF) as well as corresponding pearled kernels (PK) at each cycle were analyzed for lipid content and FA composition. The objective was to compare lipid content, FA composition, and their distribution patterns within a seed among grain species.

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Comparison among grains is necessary simply because the distribution of lipids among structural parts is known to vary with grain species; for most cereals lipids are concentrated in germ and aleurone regions, but for others, such as oats, a considerable amount is in the endosperm tissue (Banas and others 2007). Therefore, distribution patterns in the content and FA composition of lipids within a seed are expected to be different among grain species. Such information would be valuable for those who study or use cereals grains or materials made of them for improving nutritional values, storage stability, or general quality.

Materials and Methods

Cereal grain materials

Seeds of 5 grain species (barley, oat, rice, sorghum, and wheat), each with 2 varieties or lines having distinct features, a total of 10 samples, were selected and used. The name and feature for each seed sample are described in Table 1. Seed samples were passed through a screen to remove broken kernels and foreign material. For hulless oats, a screen with a code L, 5/64″ × 3/4″ (1.98 × 19.04 mm) slotted (Seedburo Equipment Co. Chicago, Ill., U.S.A.) was used. For all other 9 grains, a screen with a code M, 5.5/64" × 3/4″ (2.18 × 19.04 mm) slotted was used. The cleaned grains were not tempered before dehulling and/or abrading.

Dehulling hulled seeds prior to abrading

For effective abrading (high uniformity and less breakage), hulled seeds (1 hulled barley, 1 hulled oat, and 2 rough rice samples) had to be dehulled prior to abrading (pearling). For effective dehulling, different pieces of lab equipment had to be selected and used for different grain species. According to the procedure described previously (Liu 2007), dehulling of hulled barley was carried out by a Strong-Scott barley pearler (Seedburo) fitted with a 30 grit carborundum stone, an 8-mesh screen [8 slots per inch (25.3807 mm)] and a 1/4 hp motor providing a fixed standard speed of 1725 rpm. Hulled oat was dehulled by a Lab Huller (Model 5095, Codema, Inc., Minneapolis, Minn., U.S.A.). Hulls of rough rice were removed by repeatedly going through a lab threshing machine (Agriculex, Model SPT-1, Canada). Furthermore, the hull fraction of hulled barley or hulled oat, having about 11% (barley) or 25% (oat) of the original kernel weight, was further separated into 2 fractions by passing through a sieve with a U.S. standard mesh size of 18 (1.0-mm opening). The material on the top of the screen, termed HULL, was a light fraction consisting mainly of hulls. The material that passed the screen, termed hull fines (HF), was a heavy fines fraction, consisting mainly of fine hull, germ, pericarp, and testa. The initial weight of each seed sample for dehulling was 250 g.

Successive abrading of dehuled or original hulless grains

The dehulled kernels of hulled grains or the whole kernels of the hulless grains were abraded in a successive mode by an electric seed scarifier (Forsberg, Thief River Falls, Minn., U.S.A.) following the procedure described earlier (Liu 2007). The machine came with a standard 1/3 HP motor. It was replaced with a new motor, which had dual hp (1/3 and 1/6) corresponding to dual speeds. The high speed equaled the original factory motor speed of 1725 rpm. The low speed (1140 rpm) was chosen throughout the study for effective abrading.

During pearling, each seed sample, initially 250 g for each hulless grain or the remaining weight (< 250 g) of dehulled seeds, was put into the drum. The drum was horizontally aligned into the cylinder with the propeller fixed at the center. The motor performed at fixed and full speed (1140 rpm). The motor was stopped after roughly about 4% of grain surface (outer layer) was removed. The mixture of PK and surface material pearled off was brushed into a container. The surface material, termed PF, was then separated from PK by sifting the mixture through an 18-mesh (1.00-mm opening) screen. The abraded kernels remained on the screen were weighed. The level of outer layer removal was determined using the following equation:

$$\text{Surface removal (\%)} = [(\text{Initial sample weight} - \text{abraded kernel weight}) / \text{initial sample weight}] \times 100$$

The newly abraded kernels underwent another cycle of pearling, after collecting a small portion (about 5 g) for chemical analysis, and so on. For each cycle of pearling, in order to reach roughly a 4% surface removal level, duration of pearling for each cycle varied with grain type and sample charge size, ranging from less than 1 min to as long as 30 min. As pearling cycles progressed, sample charge size was reduced. When the kernel was reduced to the final core area of endosperm, no further pearling was possible due to the greatly reduced sample charge size. This was where pearling cycles ended. The number of pearling cycles, termed n, varied with grain types, ranging from 10 to 12. After the nth cycle of pearling, n factions of pearling fines (PF1-n) and corresponding n fractions of pearled kernels (PK1-n) were obtained, and named accordingly. The original whole kernel (either hulled seed or naked grains) is termed PK0, while dehulled kernel was termed DHK.

Chemical analysis

All samples, including fractions of surface material pearled off (PF1-n), pearled kernel fractions (PK1-n), hull fractions (HULL, HF) after dehulling, the initial whole grains (PK0) and dehulled kernels (DHK), were measured in duplicate for moisture and crude

Table 1–Oil content and fatty acid composition of 10 genotypes of 5 small grain species.[a,b,c]

Species	Genotype	Features	Oil content	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Barley	Baronesse	Hulled	2.41[e]	24.96[a]	2.01[b]	12.80[c]	52.70[b]	3.30[b]	2.79[b]
	Merlin	Hulless	3.26[c]	24.58[a]	1.80[b]	15.61[c]	50.79[b]	2.95[b]	2.11[c]
Oat	97AB7761	Hulled	3.71[b]	19.63[c]	1.55[c]	32.35[b]	42.25[d]	1.47[d]	2.75[b]
	99AB12334	Hulless	6.38[a]	18.81[c]	1.29[c]	36.52[a]	40.32[d]	1.02[d]	2.05[c]
Rice	Koshihi	Short grain	2.95[d]	23.74[a]	1.86[b]	32.88[b]	35.69[e]	1.39[d]	3.60[a]
	Bengal	Medium grain	2.97[d]	21.92[b]	1.98[a]	34.46[b]	36.66[e]	0.88[e]	3.14[a]
Sorghum	PR6E14	Red	3.77[b]	16.83[d]	2.44[a]	36.64[a]	40.10[d]	2.27[c]	1.72[d]
	PR6E6	White	3.61[b]	17.21[d]	1.85[b]	31.60[b]	45.44[c]	2.16[c]	1.74[d]
Wheat	Jefferson	Hard, red	2.18[f]	19.81[c]	1.05[d]	12.36[c]	61.50[a]	2.96[b]	1.15[e]
	Brundage	Soft, white	2.26[f]	20.78[c]	1.02[d]	12.15[c]	57.85[a]	4.12[a]	1.87[d]

[a]For naked (hulless) grains, the whole seed was used. For hulled grains (including rice), dehulled seeds were used.
[b]Fatty acid composition was expressed as% relative to total fatty acids, while oil content as% dry sample weight.
[c]Means of duplicate measurements. Column means bearing different letters differed at $P < 0.05$.

lipid contents, and FA composition. Moisture was determined according to an official method (AOAC 2002) and used to convert oil content into a dry matter basis. The crude lipid content was determined by an AOCS Official Procedure (AOCS 2005), using a fat analyzer (Model XT 10, Ankom Technology, Macedon, N.Y., U.S.A.). However, instead of using petroleum ether, hexane was used as the extracting solvent.

FA composition was measured using a previously described method (Liu and others 1995a), which involved preparing FA methyl esters by direct transmethylation and analyzing them with a gas chromatography instrument (Agilent 6890N, Agilent Technologies, Santa Clara, Calif., U.S.A). Detailed running conditions for the GC were also previously described (Liu and others 1995b). The percentage of an individual FA relative to the total FAs was expressed as area percentage of the total peak area in each sample.

Data treatments and statistical analysis

Data were treated with the JMP software, version 5 (JMP, a Business unit of SAS, Cary, N.C., U.S.A.) for calculating means, standard deviations, and averaged standard deviations. For whole or dehulled grain samples, analysis of variance (ANOVA) was conducted in order to investigate the effect of sample type (combination of species and variety) on lipid content and FA composition. The Tukey's honestly significant difference test was then conducted for pair-wise comparisons when ANOVA showed a significant effect at $P < 0.05$.

Results and Discussion

Comparisons of lipid content of whole or dehulled kernels among grains

The main classes of cereal lipids are triacylglycerides, glycolipids, and phospholipids. Triglycerides are nonpolar and predominant in cereals. In the present study, the lipid content was measured by extracting with hexane, a nonpolar solvent. Although a small portion of polar lipids could be extracted by hexane, the major portion of the lipids extracted would be nonpolar. In this regard, the term oil can also be used. The oil content in the 10 grains was relatively lower (Table 1), ranging from 2.18% to 6.38%, as compared with legumes and oilseeds. Among 5 grain species, oats had the highest lipid content, followed by sorghums and the rest of the 3 (barley, rice, and wheat), which had similar oil content. Varietal difference was also noticed in barleys and oats. Note that in this study, for hulled grains (including 1 hulled barley, 1 hulled oat, and 2 rough rice samples), DHK were used instead of whole kernels (PK0) since the hull or husk is nonedible part of the grain. This also makes comparison easier between hulled and hulless grains. Otherwise, the presence of hulls would reduce the oil content of hulled grains to some extent. Data on oil content of 5 grain species in this study are agreeable with many previous studies (Price and Parsons 1975; Hargin and Morrison 1980).

Comparisons of FA composition of whole or dehulled kernels among grains

FA composition was measured by a method of direct methylation by which lipids were derivatized *in situ* (no solvent extraction was made). Thus, the FA composition is considered to represent that of total lipids, rather than any particular types of lipids (nonpolar triclycerides, polar glycolipids, and phyospholipids). Similar to oilseeds and legumes, all 10 grains tested contained 5 major FAs, including palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) acid. Several other FAs were also detected, but at much lower concentrations, including myristic (C14:0), palmitoleic (C16:1), arachidic (C20:0), eicosanoic (C20:1), behenic (C22:0), erucic (C22:1), lignoceric (C24:0), and nervonic (C24:1) acids. Collectively, they were grouped and termed as "Others" in Table 1. For most FAs, the varietal difference was not as significant as the difference among species. Rice, oat, and sorghum showed a similar FA composition, while barley and wheat shared a similar one. Rice, oat, and sorghum had higher relative % of C18:1 (31.60 to 36.64) than barley and wheat (12.15 to 15.61) and lower relative% of C18:2 (35.69 to 45.44 compared with 50.79 to 61.50). In fact, for oats, rice, and sorghum, in term of relative %, the range for C18:1 (31.60 to 36.64) was just slightly lower than that for C18:2 (35.69 to 45.44). All grains had medium% of palmitic acid (17.21 to 24.96), and relatively lower% of C18:0 (1.02 to 2.44) and C18:3 (0.88 to 3.30). The summary value of all other FAs ranged from 1.14% to 3.60% for all samples.

Lindberg and others (1964) compared the FA composition of rye, wheat, barley, and oats. They found that all crops contained palmitic, oleic, and linoleic as the major acids, but oats contained more C18:1 and less C18:2 than the others. They also noticed that the FA composition of the 2 oat varieties was similar. Price and Parsons (1975) compared contents and FA composition of lipids in seven grains (barley, corn, oats, rye, sorghum, triticale, and wheat) and found that C18:2 was the major FA present, although oats and sorghum were lower. The current data on FA composition of small grains are consistent with Lindberg and others (1964), Price and Parsons (1975), as well as several others on rice (Kitta and others 2005), oats (Young and others 1977; Price and Parsons 1979; Zhou and others 1998), barley (Price and Parsons 1979; Osman and others 2000), wheat (Welch 1975), and sorghum (Osman and others 2000; Mehmood and others 2008). Major disagreement among studies, if exists, relate to the linolenic content in certain grains; some previous reports showed higher C18:3 values than that of the current study. This can be attributed to the fact that this FA is prone to oxidation and thus affected most by differences in the sample storage history as well as analytical methodologies. It can also be partially attributed to observed effects of varieties and growing conditions on FA composition of grains (Saastamoinen and others 1989).

Changes in oil content as pearling cycles progressed

Through pearling cereal grains sequentially by the seed scarifier, a relationship between oil content in the surface layer abraded off (pearling fines or PF) at each cycle of pearling, and the cumulative level of surface removal could be established for each of the 10 grains (Figure 1 and 2). Such relationship essentially describes the distribution of oil content within a seed. At the same time, a relationship between oil content in pearled kernel (PK) at each cycle of pearling and the cumulative level of surface removal could also be established. Although this relationship does not describe the distribution of oil content within a seed, it does provide information on lipid content of remaining kernels as pearling cycles progressed. Such information is also important since for most grains, it is the pearled kernel that is commonly consumed. For PK, the data points in Figure 1 and 2 corresponding to the 0% removal level refer to the oil content of the initial whole grain, while the data points corresponding to the highest cumulative removal level (60.51% to 70.57%, depending on grain species and genotypes) refers to the oil content of the inner core of a seed.

Examination of hulless barley (Merlin) (Figure 1A, circle markers) shows that the oil yield in the intact seed (PK0) was 3.26%, but the oil content in PF1 (resulting from the first cycle of pearling)

was 12.19%, the highest of all fractions. As the cumulative level of surface layer removal increased (that is, as the pearling cycle progressed), the oil content in PF fractions (Figure 1A, empty circles) decreased sharply between 0% to about 38% surface removal (after 6 cycles of pearling), the value at about 38% surface removal (PF6) became 2.04%, which was lower than the value of whole kernel

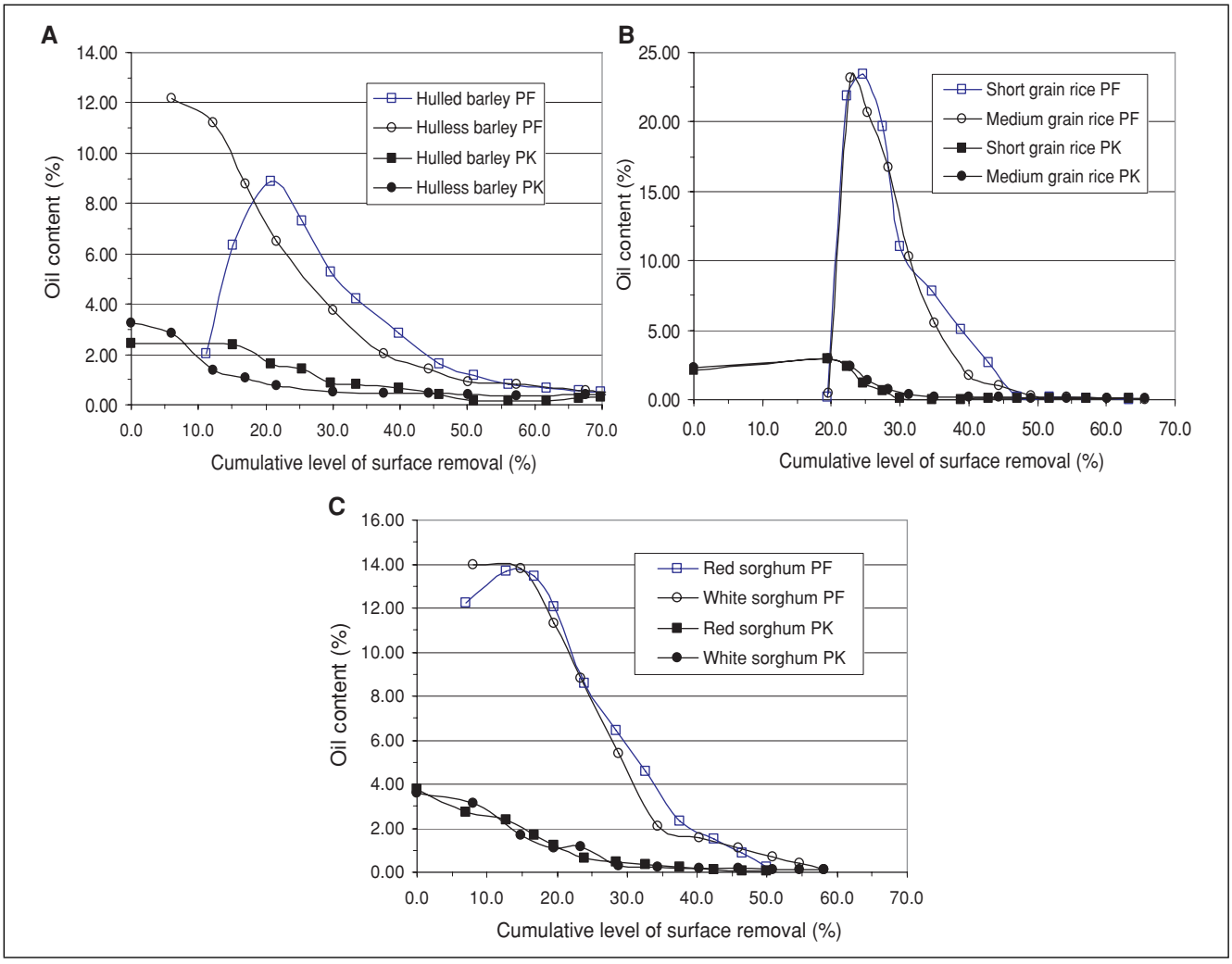

Figure 1–Oil content of pearling fines (PF) and pearled kernels (PK) in barley (A), rice (B), and sorghum (C), each having 2 varieties or lines.

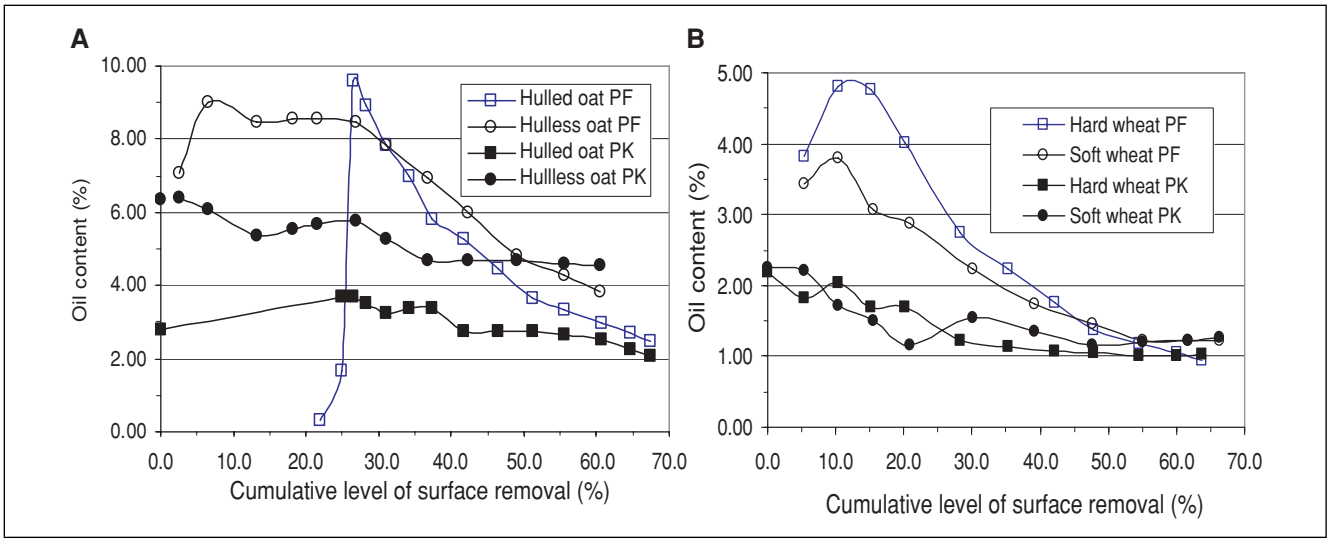

Figure 2–Oil content in pearling fines (PF) and pearled kernels (PK) of oats (A) and wheat (B), each having 2 varieties or lines.

(3.26%). These outer layers with fast decreasing oil content corresponded to the structural parts of pericarp, seed coat, aleurone and germ, the former 3 collectively known as bran. From this point, further pearling inwards also led to a gradual decrease in oil content, but at a much reduced rate. At about 70% surface removal, the oil content in the material of this seed section was only 0.50%, representing endosperm composition. The above pattern of decrease in oil content describes the distribution pattern of oil within the seed of this particular barley variety.

For PK fractions of the hulless barley (Figure 1A, solid circles), as the level of surface removal progressed from 0% to about 12% (after 2 cycles of pearling), with resulting PK2 representing about 88% of the original kernel mass, the value of oil content quickly decreased from 3.26% (PK0) to 1.37% (PK2). The sharp decrease in oil yield in PK fractions was mainly due to removal of several outer layers (PF) that had the larger concentration of oil. The oil yield of PF fractions obtained by initial several cycles of pearling was several times greater than that of corresponding PK. From here, further pearling led to further decrease in oil content. However, at about 38% removal, corresponding to 62% of original kernel mass for PK6, the oil content reached a flat bottom level of 0.47%, representing endosperm composition. When the pearling cycle reached to about 70% surface levels, with resulting PK11 representing about 30% of the original kernel mass, the oil content was still measurable, at 0.42%.

With increasing cycles of pearling, the hulled barley Baronesse (Figure 1A, square markers) followed similar patterns of changes in oil content as the hulless variety, when hulls were removed and the DHK was treated as if it was PK0 of hulless barley. This is because the hull fraction had much lower oil content to than other PF fractions, even lower than PK0. Studies have documented that as a structural part, cereal hulls have a different composition than other parts of grains (Youngs and others 1977; Price and Parsons 1979).

Rice (Figure 1B) and sorghum (Figure 1C) followed similar changing patterns as barley for both PF and PK fractions (Figure 1A). They are featured by (1) rapid reduction in the oil content during the first few cycles of pearling, followed by a gradual decrease to a flat bottom; (2) the oil content in the first few PF fractions were several times higher than the corresponding PK fractions. The observations indicate that for barley, rice, and sorghum, the oil is largely concentrated in the germ and the bran region. The inner endosperm contained much less oil. Varietal difference in distribution patterns within a species was not obvious regardless of the difference in the initial oil content.

In contrast, oats showed a different changing pattern in oil content as the pearling cycle progressed (Figure 2A). Examination of hulless oats (Line 99AB12334) (Figure 2A, circle markers) indicates that the oil yield in the intact seed (PK0) was 6.35% while the oil content in PF1 (resulting from the 1st layer of pearling) was 7.05%. The difference between the 2 fractions was only 0.70%. As the cumulative level of surface layer removal increased, the oil content in both PF and PK fractions decreased gradually all the way to about 60% removal level where the fines fraction (PF12) still had an oil content of 3.89% and the remaining kernel fraction (PK12) had an oil content of 4.57. The difference in the oil content between the outer surface and the inner tissue was much less than that observed with barley, rice, and sorghum. Even though the initial oil content was much less, the hulled oat line (97AB7761) showed a similar changing pattern to the hulless line, as the cycle of pearling increased. After hulls were removed, DHK was treated as if it was PK0 of hulless oat (Figure 2A).

This changing pattern of oil in oats is featured by (1) the gradual reduction in the oil content throughout the whole cycles of pearling; (2) the oil content in the first few PF fractions were just slightly higher than the corresponding PK fractions. The observations indicate that for oats, the oil is less concentrated in the bran region and that the inner endosperm contained a substantial amount of oil. Again, varietal difference in oil distribution patterns within a species was not obvious regardless of difference in the initial oil content.

The oil changing pattern of wheat (Figure 2B) fell in between the pattern of oats and the pattern of barley, rice, and sorghum, although it resembled more to that of oats (Figure 2A). There was some difference between soft and hard wheat, particularly with regard to changes in the first few PF fractions. For hard wheat, the oil yield increased initially, reached a peak, and then decreased. Regardless, the oil content in inner core regions (endosperm) still had about 45% of the whole grain oil content (about 1.0% compared with 2.2%). This % value is higher than barley, rice, and sorghum but lower than oats.

The observed oil distribution patterns in PF and PK fractions and differences among 5 species of grains in this study were generally consistent with previous findings of oil distribution within structural parts of certain grains. Youngs and others (1977) fractionated seeds of 2 oat varieties into groats, hulls, bran, endosperm, scutellum, and embryonic axis. They found that the content of ether extracted lipids in these fractions were 8.0, 2.3, 9.5, 6.8, 20.6, and 12.6% (dry basis), respectively, for one variety, and 5.5, 2.0, 6.4, 5.2, 20.4, 10.6%, respectively, for another variety. In both varieties, the difference in lipid content between endosperm and bran tissue was substantially lower than those of most other grains. Price and Parsons (1979) measured content and composition of lipids in the embryonic axis, bran-endosperm, and hull fractions of hulless barley and hulless oat caryopses, and found that total lipid content of "Prilar Hulless" barley was 3.2% and "James Hulless" oats was 7.2%**.** Total lipid content of embryo, bran-endosperm, and hull fractions of barley was 19.6%, 2.8%, and 2.4%, respectively, and of oats was 21.2%, 7.1%, and 4.4%, respectively. Although they did not separate bran from endosperm, they reasoned that the relatively high total lipid content of oats compared to barley indicates the presence of considerably more lipids in the endosperm fraction of the oat seed than barley. Later, Banas and others (2007) also showed that the majority of oat grain oil (86% to 90%) resides in the endosperm tissue. In contrast, the amount of lipid in endosperm of brown rice is only 22%, while bran and embryo contain 56% and 22%, respectively (Brandbury and Collins 1982).

Changes in FA composition as pearling cycles progressed

Similar to the oil content, through pearling sequentially by the seed scarifier, a relationship between FA composition in the surface layer abraded off (pearling fines or PF) at each cycle of pearling and the accumulated level of surface removal could be established for each of 10 grains (Table 2 to 6). Such relationship essentially describes the distribution of each FA in relative% within a seed. At the same time, relationships between FA composition in the remaining pearled kernel (PK) at each cycle of pearling and the accumulated level of surface removal could also be established. This relationship does not describe distribution of FA composition within as seed, but conveys information on lipid composition of remaining kernels after progressive abrading.

The results revealed that as pearling cycles progressed, FA composition changed. In other words, FA composition varied with

Table 2–Fatty acid composition in pearling fines, whole and dehulled kernels, pearled kernels of 2 barley varieties.[a,b]

	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Fraction	**Baronesse (hulled)**							**Merlin (hulless)**						
HULL	11.09	26.83	1.06	13.35	44.08	6.68	6.64							
HF	15.09	24.68	0.96	13.48	50.20	6.47	3.56							
PF1	20.75	21.19	1.42	17.60	53.45	3.39	2.39	5.94	20.72	1.53	20.91	50.22	3.82	2.07
PF2	25.39	21.67	1.50	16.94	53.91	3.08	2.30	12.11	20.65	1.50	20.51	51.10	3.45	2.03
PF3	29.67	22.49	1.57	16.14	53.81	2.93	2.30	16.94	21.77	1.57	19.31	51.07	3.19	2.13
PF4	33.44	23.20	1.61	15.33	53.84	2.84	2.24	21.66	22.86	1.63	18.13	51.05	2.95	2.22
PF5	39.79	24.21	1.74	14.10	53.81	2.67	2.34	29.99	24.38	1.71	16.32	50.78	2.69	2.18
PF6	45.80	26.11	1.93	12.03	53.75	2.45	2.34	37.55	27.04	1.99	13.59	50.45	2.42	2.07
PF7	51.01	27.05	2.17	10.82	53.56	2.31	2.46	44.18	29.26	1.96	11.40	50.25	2.11	2.09
PF8	56.05	27.96	2.41	9.65	53.39	2.18	2.58	50.10	30.46	2.07	9.94	50.01	1.88	2.24
PF9	61.82	29.01	2.68	8.31	53.18	2.03	2.71	57.22	31.12	2.15	8.90	50.15	1.80	2.21
PF10	66.50	29.49	3.04	8.00	52.78	1.99	2.54	67.56	32.07	2.26	7.40	50.35	1.69	2.18
PF11	69.78	29.83	3.28	7.78	52.50	1.96	2.42	70.57	31.99	2.30	7.29	50.68	1.71	2.11
PK0	0.00	24.96	2.01	12.80	52.71	3.30	2.79	0.00	24.58	1.80	15.61	50.79	2.95	2.11
DHK	15.09	25.66	2.36	12.07	53.08	2.57	2.81							
PK1	20.75	26.47	2.54	10.95	53.05	2.44	2.81	5.94	26.27	1.95	13.62	50.41	2.62	2.61
PK2	25.39	27.14	2.68	10.04	53.03	2.33	2.82	12.11	27.72	2.02	11.87	50.29	2.39	2.70
PK3	29.67	27.75	2.82	9.20	53.01	2.23	2.83	16.94	28.85	2.08	10.49	50.19	2.21	2.77
PK4	33.44	28.29	3.01	8.73	52.47	2.20	3.01	21.66	29.96	2.14	9.15	50.10	2.04	2.84
PK5	39.79	28.61	3.21	8.21	52.29	2.11	3.13	29.99	30.43	2.26	8.36	50.20	1.99	2.75
PK6	45.80	28.85	3.42	7.93	52.09	2.06	3.13	37.55	30.87	2.38	7.65	50.29	1.95	2.66
PK7	51.01	29.05	3.60	7.69	51.91	2.01	3.12	44.18	31.24	2.48	7.03	50.37	1.92	2.58
PK8	56.05	29.25	3.78	7.45	51.74	1.97	3.11	50.10	31.58	2.57	6.47	50.45	1.89	2.52
PK9	61.82	29.31	3.90	7.46	51.32	2.04	3.08	57.22	31.76	2.58	6.27	50.14	1.91	2.67
PK10	66.50	29.07	4.14	7.62	51.19	2.11	2.84	67.56	32.02	2.61	5.97	49.70	1.96	2.89
PK11	69.78	29.27	4.24	7.65	50.86	2.15	2.69	70.57	32.10	2.61	5.89	49.57	1.97	2.95

[a]Fatty acid was expressed as % relative to total fatty acids. HF = hull fines; PF = pearling fines; PK = pearled kernels, PK0 = whole kernels; DHK = dehulled kernels.
[b]Means of duplicate measurements, with an average standard deviation of 0.13 for oil content and 0.24 for fatty acid composition.

Table 3–Fatty acid composition in pearling fines, whole and dehulled kernels, and pearled kernels of 2 oat lines.[a,b]

	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Fraction	**97AB7761 (hulled)**							**99AB12334 (hulless)**						
HULL	22.00	30.70	3.30	21.54	33.05	4.08	7.33							
HF	25.00	25.77	2.39	27.81	34.06	4.15	5.82							
PF1	26.44	15.93	0.88	38.12	40.64	2.58	1.85	2.66	15.58	0.81	42.98	36.63	2.09	1.92
PF2	28.35	16.36	0.96	37.45	41.04	2.22	1.97	6.46	16.10	1.01	42.29	37.58	1.18	1.85
PF3	31.10	16.79	1.03	36.78	41.44	1.86	2.10	13.30	16.70	1.08	40.85	38.49	1.03	1.85
PF4	34.14	17.22	1.11	36.11	41.84	1.50	2.23	18.16	16.80	1.12	40.51	38.71	1.00	1.87
PF5	37.39	17.62	1.19	35.46	42.03	1.41	2.29	21.58	16.94	1.12	40.05	39.00	0.99	1.89
PF6	41.82	18.17	1.30	34.59	42.29	1.29	2.36	26.82	17.15	1.14	39.34	39.46	0.99	1.93
PF7	46.48	18.76	1.41	33.90	42.34	1.21	2.38	31.07	17.33	1.16	38.83	39.76	1.00	1.93
PF8	51.28	19.37	1.53	33.18	42.39	1.13	2.40	36.83	17.67	1.19	38.09	40.12	0.95	2.00
PF9	55.53	19.59	1.59	33.02	42.29	1.11	2.40	42.41	18.00	1.21	37.37	40.46	0.90	2.06
PF10	60.63	19.97	1.65	32.32	42.58	1.10	2.38	49.12	18.26	1.25	37.03	40.53	0.88	2.05
PF11	64.61	20.01	1.67	32.23	42.61	1.09	2.40	55.50	18.50	1.28	36.71	40.59	0.87	2.04
PF12	67.49	19.94	1.67	32.27	42.63	1.08	2.41	60.51	18.66	1.33	36.78	40.41	0.83	1.99
PK0	0.00	19.63	1.55	32.35	42.25	1.47	2.75	0.00	18.81	1.29	36.52	40.32	1.02	2.05
DHK	25.00	20.10	1.56	31.03	43.45	1.39	2.48							
PK1	26.44	19.75	1.54	32.11	42.80	1.33	2.46	2.66	18.78	1.27	36.78	40.20	0.95	2.01
PK2	28.35	20.02	1.58	31.60	43.03	1.29	2.48	6.46	19.01	1.34	36.43	40.31	0.94	1.97
PK3	31.10	20.22	1.48	31.35	43.49	1.19	2.26	13.30	19.23	1.36	36.03	40.52	0.92	1.95
PK4	34.14	20.45	1.37	31.08	44.00	1.08	2.02	18.16	19.53	1.37	35.52	40.72	0.91	1.95
PK5	37.39	20.69	1.25	30.79	44.54	0.96	1.76	21.58	19.74	1.38	35.16	40.86	0.90	1.95
PK6	41.82	21.02	1.10	30.39	45.28	0.80	1.42	26.82	19.85	1.40	35.20	40.71	0.88	1.97
PK7	46.48	21.42	1.32	29.78	44.90	1.00	1.58	31.07	19.93	1.42	35.23	40.58	0.86	1.98
PK8	51.28	21.49	1.45	29.03	45.23	1.06	1.75	36.83	20.10	1.44	34.98	40.59	0.86	2.03
PK9	55.53	21.59	1.51	28.72	45.22	1.12	1.85	42.41	20.11	1.47	34.95	40.57	0.85	2.04
PK10	60.63	21.70	1.59	28.35	45.20	1.19	1.96	49.12	20.32	1.49	34.69	40.59	0.83	2.08
PK11	64.61	21.39	1.77	28.41	44.98	1.22	2.23	55.50	20.52	1.51	34.45	40.60	0.82	2.11
PK12	67.49	21.16	1.91	28.45	44.82	1.25	2.42	60.51	20.36	1.51	34.63	40.58	0.84	2.08

[a]Fatty acid was expressed as % relative to total fatty acids. HF = hull fines; PF = pearling fines; PK = pearled kernels; PK0 = whole kernels; DHK = dehulled kernels.
[b]Means of duplicate measurements, with an average standard deviation of 0.13 for oil content and 0.24 for fatty acid composition.

fractions obtained. Since FA composition was expressed as % relative to total FAs, with increasing cycle of pearling, even though the oil content in fractions of both PF and PK decreased, the changing patterns of FAs were mixed: some decreased, others increased, and still others remained relatively unchanged. For easy comparison, the changing patterns of 5 major FAs and the remaining others with increasing surface removal were tabulated in Table 7 with several short symbols, along with the changing pattern of oil content. In general, for all 10 grains with varying species and genotypes, as the pearling cycle increased, in fractions of both PF and PK, saturated FAs (C16:0 and C18:0) increased, C18:1 and C18:3 decreased, C18:2 and the remaining others had mixed

Table 4–Fatty acid composition in pearling fines, whole and dehulled kernels, and pearled kernels of 2 rice varieties.[a,b]

	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Fraction	Koshihi (short grain)							Bengal (medium grain)						
HULL	19.50	40.27	3.53	19.35	17.39	1.84	14.01	19.63	24.18	2.34	31.80	32.32	1.01	7.43
PF1	22.25	17.61	1.63	44.73	29.86	1.09	4.80	22.71	16.30	1.48	39.97	36.82	0.93	4.11
PF2	24.67	18.70	1.88	41.14	33.06	1.11	3.85	25.35	16.74	1.62	40.39	36.24	0.91	3.70
PF3	27.44	19.29	1.91	40.45	33.39	1.09	3.60	28.36	17.25	1.78	40.86	35.58	0.88	3.24
PF4	30.00	19.83	1.95	39.82	33.69	1.08	3.36	31.38	18.02	1.87	40.12	35.48	0.86	3.16
PF5	34.71	21.53	1.85	37.51	34.38	1.09	3.22	34.92	19.15	1.94	38.75	35.60	0.83	3.09
PF6	38.82	26.37	1.76	30.74	36.20	1.18	2.86	39.96	23.27	2.06	33.59	36.55	0.78	2.51
PF7	42.89	31.15	1.68	24.04	38.00	1.28	2.51	44.38	27.55	2.26	28.70	36.76	0.73	2.20
PF8	47.13	34.68	1.71	20.79	37.73	1.29	2.22	49.08	32.09	2.48	23.51	37.00	0.67	1.86
PF9	51.81	36.82	1.71	18.78	37.64	1.31	1.98	54.32	35.39	2.70	20.29	36.77	0.68	1.42
PF10	57.05	37.45	1.79	17.47	38.33	1.38	1.76	60.19	37.20	2.90	18.25	36.86	0.69	1.21
PF11	63.29	37.29	1.79	16.70	39.34	1.47	1.56	65.64	38.42	3.17	17.04	36.30	0.69	1.54
PK0	0.00	23.74	1.86	32.88	35.69	1.39	3.60	0.00	21.92	1.98	34.46	36.66	0.88	3.14
DHK	19.50	23.79	1.80	32.72	36.27	1.40	3.20	19.63	21.65	1.94	34.74	36.90	0.90	2.91
PK1	22.25	25.43	1.74	29.00	38.36	1.51	2.93	22.71	23.02	2.13	33.31	36.97	0.91	2.53
PK2	24.67	26.87	1.68	25.74	40.20	1.61	2.70	25.35	25.28	2.36	30.18	37.48	0.87	2.39
PK3	27.44	28.89	1.62	22.04	42.07	1.76	2.14	28.36	28.33	2.43	25.57	38.87	0.89	2.00
PK4	30.00	29.86	1.57	19.90	43.14	1.86	2.07	31.38	31.39	2.50	20.94	40.27	0.91	1.62
PK5	34.71	31.63	1.47	15.94	45.10	2.04	1.95	34.92	34.05	2.74	17.58	40.72	0.88	1.34
PK6	38.82	31.88	1.47	15.25	45.58	2.10	1.80	39.96	35.03	2.74	15.88	41.37	0.93	1.20
PK7	42.89	32.12	1.47	14.58	46.05	2.16	1.65	44.38	35.69	2.80	14.99	41.44	0.95	1.21
PK8	47.13	32.38	1.48	13.88	46.54	2.22	1.50	49.08	36.39	2.86	14.04	41.51	0.97	1.22
PK9	51.81	32.33	1.53	13.82	46.39	2.23	1.67	54.32	36.41	2.94	13.48	42.01	1.04	1.19
PK10	57.05	32.27	1.86	13.65	46.08	2.31	1.88	60.19	36.43	3.03	12.86	42.58	1.12	1.15
PK11	63.29	32.21	2.25	13.44	45.71	2.41	2.12	65.64	37.79	3.41	12.48	41.50	1.10	1.15

[a]Fatty acid was expressed as % relative to total fatty acids. PF = pearling fines; PK = pearled kernels; PK0 = whole kernels; DHK = dehulled kernels.
[b]Means of duplicate measurements, with an average standard deviation of 0.13 for oil content and 0.24 for fatty acid composition.

Table 5–Fatty acid composition in pearling fines, whole and pearled kernels of 2 sorghum lines.[a,b]

	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Fraction	PR6E14 (red)							PR6E6 (white)						
PF1	7.03	14.59	2.02	39.71	38.72	2.25	2.71	7.96	15.07	1.50	31.77	47.64	2.19	1.85
PF2	12.76	14.93	2.14	38.41	39.41	2.64	2.48	14.79	15.29	1.62	31.66	47.28	2.28	1.87
PF3	16.68	15.07	2.27	37.63	40.26	2.42	2.35	19.52	15.55	1.65	32.27	46.54	2.18	1.81
PF4	19.57	15.21	2.02	37.63	40.79	2.13	2.22	23.34	15.77	1.67	32.76	45.95	2.10	1.76
PF5	23.90	15.70	1.88	37.86	40.53	1.92	2.12	28.81	16.16	1.70	33.44	45.04	1.95	1.72
PF6	28.48	16.29	2.03	38.01	39.67	1.84	2.18	34.38	16.74	1.69	33.94	44.32	1.75	1.57
PF7	32.58	16.73	2.20	37.99	39.02	1.83	2.23	40.35	18.12	1.90	33.58	43.07	1.73	1.61
PF8	37.48	18.37	2.58	37.23	37.63	1.88	2.32	45.98	21.63	2.40	32.17	40.33	1.82	1.66
PF9	42.36	20.11	3.05	36.44	36.01	2.00	2.40	50.80	24.63	2.82	30.96	37.99	1.90	1.71
PF10	46.36	21.82	3.47	35.37	34.71	2.06	2.57	54.61	27.52	3.22	29.66	35.83	1.95	1.82
PF11	49.88	25.73	4.07	32.82	32.76	1.99	2.62	58.08	29.61	3.55	28.83	34.15	1.97	1.89
PK0	0.00	16.83	2.44	36.64	40.10	2.27	1.72	0.00	17.21	1.85	31.60	45.44	2.16	1.74
PK1	7.03	17.46	2.85	35.26	40.39	2.41	1.65	7.96	18.05	2.02	31.54	44.56	2.15	1.69
PK2	12.76	17.84	2.79	34.96	40.48	2.27	1.65	14.79	19.04	2.11	31.40	43.77	2.05	1.62
PK3	16.68	18.10	2.76	34.76	40.55	2.18	1.66	19.52	19.74	2.17	31.31	43.23	1.99	1.57
PK4	19.57	18.90	3.08	34.12	40.05	2.16	1.69	23.34	20.94	2.34	30.78	42.25	2.04	1.64
PK5	23.90	19.91	3.48	32.99	39.48	2.31	1.83	28.81	22.66	2.58	30.04	40.85	2.13	1.75
PK6	28.48	20.95	3.78	31.70	39.29	2.43	1.85	34.38	24.08	2.78	29.14	40.08	2.20	1.72
PK7	32.58	21.88	4.06	30.55	39.12	2.53	1.87	40.35	25.70	3.07	28.11	39.13	2.34	1.66
PK8	37.48	22.40	4.42	29.34	39.30	2.65	1.90	45.98	27.24	3.35	27.13	38.22	2.46	1.60
PK9	42.36	23.53	4.70	27.57	39.43	2.73	2.04	50.80	27.73	3.39	26.79	37.97	2.48	1.65
PK10	46.36	24.21	4.96	26.68	39.22	2.76	2.17	54.61	28.12	3.42	26.52	37.76	2.50	1.68
PK11	49.88	24.81	5.18	25.90	39.04	2.78	2.29	58.08	28.39	3.34	26.18	37.76	2.47	1.88

[a]Fatty acid composition was expressed as % relative to total fatty acids. PF = pearling fines; PK = pearled kernels; PK0 = whole kernels.
[b]Means of duplicate measurements, with an average standard deviation of 0.13 for oil content and 0.24 for fatty acid composition.

changing patterns, depending on grain species and genotype, but mostly remained unchanged or changed slightly. Also for all the grains, the changing patterns of PK followed those of PF fractions, although in some cases at a reduced degree.

The change in FA composition within a cereal seed observed in this study can be attributed to heterogeneous distribution of various types of lipids within the seed found previously on wheat (Hargin and Morrison 1980). More importantly, the above new finding is significant. For example, we all know that removing surface layers (bran) of grains, which is commercially practiced (such as wheat milling, rice polishing, and barley pearling), can improve storage stability of the remaining kernels by reducing its lipid content. For the first time, this study shows that the other important reason is that removing surface layers also changes FA composition of the remaining kernels toward more stable lipids (increasing saturated FAs while decreasing unsaturated).

Relationship in distribution patterns within a seed between oil content and FA composition

Careful examination of Table 7 shows that in terms of changing intensity, among 5 grain species, for both PF and PK fractions, with increasing level of surface removal, barley, rice, sorghum had significant changes in FA composition, while wheat and oat showed only slight changes. Within each species, varietal effect

Table 6–Fatty acid composition in pearling fines, whole and pearled kernels of 2 wheat varieties.[a,b]

	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others	Removal level (%)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Fraction	Jefferson (hard, red)							Brundage (soft, white)						
PF1	5.44	18.13	0.90	15.07	59.59	4.10	1.34	5.34	20.09	0.87	13.60	55.52	5.48	2.74
PF2	10.37	17.99	0.84	14.75	60.87	3.55	1.10	10.26	19.65	0.83	14.12	56.48	4.91	2.04
PF3	15.19	18.40	0.86	14.33	61.21	3.35	1.10	15.57	19.87	0.83	13.87	56.81	4.63	1.95
PF4	20.09	18.91	0.90	14.10	61.37	3.07	1.08	20.89	20.09	0.83	13.62	57.15	4.36	1.85
PF5	28.27	19.47	0.87	12.68	62.75	2.83	0.92	30.09	20.35	0.89	13.13	57.68	4.05	1.77
PF6	35.27	19.95	0.85	11.47	63.94	2.62	0.79	39.10	20.60	0.95	12.65	58.20	3.76	1.69
PF7	42.12	20.04	1.00	10.61	64.43	2.63	0.75	47.71	20.86	1.05	12.13	58.32	3.67	1.69
PF8	47.78	20.51	1.06	10.66	63.68	2.53	0.82	54.96	21.07	1.13	11.69	58.41	3.59	1.70
PF9	54.51	21.07	1.12	10.71	62.78	2.41	0.91	61.64	21.27	1.20	11.29	58.51	3.52	1.71
PF10	59.93	21.39	1.16	10.34	62.70	2.44	0.90	66.24	21.71	1.19	10.96	58.31	3.51	1.82
PF11	63.68	21.55	1.21	9.96	62.70	2.48	0.91							
PK0	0.00	19.81	1.05	12.36	61.50	2.96	1.14	0.00	20.78	1.02	12.15	57.85	4.12	1.87
PK1	5.44	19.96	1.05	11.81	62.14	2.86	1.11	5.34	20.84	1.03	11.95	58.13	4.02	1.92
PK2	10.37	20.10	1.05	11.31	62.72	2.77	1.08	10.26	20.90	1.05	11.76	58.39	3.93	1.97
PK3	15.19	20.21	1.09	11.14	62.82	2.70	1.02	15.57	21.06	1.12	11.62	58.52	3.80	1.76
PK4	20.09	20.33	1.14	10.97	62.93	2.63	0.95	20.89	21.18	1.15	11.51	58.48	3.73	1.81
PK5	28.27	20.55	1.17	10.55	63.11	2.58	0.93	30.09	21.40	1.20	11.30	58.40	3.60	1.90
PK6	35.27	20.75	1.19	10.19	63.27	2.54	0.92	39.10	21.27	1.20	10.95	58.80	3.63	1.96
PK7	42.12	20.94	1.24	10.13	63.09	2.52	0.87	47.71	21.41	1.25	11.01	58.41	3.63	1.92
PK8	47.78	21.10	1.29	10.08	62.94	2.51	0.84	54.96	21.52	1.29	11.06	58.08	3.63	1.88
PK9	54.51	21.15	1.29	10.12	62.71	2.59	0.85	61.64	21.63	1.33	11.11	57.78	3.62	1.85
PK10	59.93	21.18	1.29	10.15	62.52	2.66	0.85	66.24	21.72	1.35	11.11	57.63	3.71	1.69
PK11	63.68	21.20	1.29	10.17	62.39	2.71	0.86							

[a]Fatty acid composition was expressed as % relative to total fatty acids. PF = pearling fines; PK = pearled kernels; PK0 = whole kernels.
[b]Means of duplicate measurements, with an average standard deviation of 0.13 for oil content and 0.24 for fatty acid composition.

Table 7–Changing trends in oil content and fatty acid composition of pearling fines and pearled kernels with culmulative levels of surface layer removal from 10 genotypes of 5 small grain species.[a]

Species	Genotype	Features	Fractions	Removal level (%)	Oil content (% dm)	C16:0	C18:0	C18:1	C18:2	C18:3	Others
Barley	Baronesse	Hulled	Pearling fines	↑	↓	↑	↑	↓	↔	↓	↔
			Pearled kernels	↑	↓	↑	↑	↓	↔	↓	↔
	Merlin	Hulless	Pearling fines	↑	↓	↑	↑	↓	↔	↓	↔
			Pearled kernels	↑	↓	↑	↑	↓	↔	↓	↔
Rice	Koshihi	Short grain	Pearling fines	↑	↓	↑	↔	↓	↑	↑ S	↓
			Pearled kernels	↑	↓	↑	↔	↓	↑	↑ S	↓
	Bengal	Medium grain	Pearling fines	↑	↓	↑	↑	↓	↔	↔	↓
			Pearled kernels	↑	↓	↑	↑	↓	↑	↔	↓
Oat	97AB7761	Hulled	Pearling fines	↑	↓	↑ S	↑ S	↓ S	↑ S	↓ S	↔
			Pearled kernels	↑	↑ S	↔	↔	↓ S	↔	↔	↔
	99AB12334	Hulless	Pearling fines	↑	↓	↑ S	↑ S	↓ S	↑ S	↓ S	↔
			Pearled kernels	↑	↑ S	↑ S	↑ S	↓ S	↔	↓ S	↔
Wheat	Jefferson	Hard, red	Pearling fines	↑	↓	↑ S	↑ S	↓	↔	↓ S	↓ S
			Pearled kernels	↑	↑ S	↑ S	↑ S	↓ S	↔	↔	↓ S
	Brundage	Soft, white	Pearling fines	↑	↓	↑ S	↑ S	↓	S↑	↓	↓ S
			Pearled kernels	↑	↑ S	↔	↑ S	↔	↔	↔	↔
Sorghum	PR6E14	Red	Pearling fines	↑	↓	↑	↑	↓	↓	↓ S	↔
			Pearled kernels	↑	↓	↑	↑	↓	↔	↔	↑ S
	PR6E6	White	Pearling fines	↑	↓	↑	↑	↓ S	↓	↓ S	↔
			Pearled kernels	↑	↓	↑	↑	↓	↓	↔	↔

[a]Changing trends: ↑ = increase; ↑ S = increase slightly; ↓ = decrease; ↓ S = decrease slightly; ↔ = flat.

was insignificant. Such differences in the changing intensity of FA composition among grain species correspond to those in oil distribution with a seed just discussed (Figure 1 and 2). In other words, there is a relationship between FA distribution and oil distribution within a cereal grain. The former is governed by the latter. For barley, rice, and sorghum, oil is mostly concentrated in germ and bran region, while endosperm has much less oil. Thus, they also share similar FA distribution patterns, with rapid changing rates as the pearling cycle progressed inward. In contrast, for oats and for wheat to some extent, oil is less concentrated in the bran region, while endosperm had a substantial amount of oil. Thus, they also share similar FA distribution patterns, with much lower changing rates as the pearling cycle progressed inward.

Finally, the present study used a unique lab abrading method that could remove surface layers of cereal grains, layer by layer, and then measured and compared the lipid content as well as FA composition in several PF fractions and corresponding abrading kernels of 10 small grains. The methodology did not give botanically homogenous fractions. Because of differences in the kernel shape and size among individual seeds of same sample, fractions obtained by pearling might not necessarily contain the same structural parts based on levels of surface removal. This is particularly true for seeds of barley, oats, and wheat, in which some structural parts such as pericarp, aleurone, and so on remained in the creases of the kernels even after several layers of fractions have been removed. However, this method was the most practical way to obtain different fractions that represented different structure parts, thus allowing a comparison to be made on not only the concentration of oil and a particular FA, fraction by fraction within a seed, but also the distribution pattern for a particular attribute measured among grains. In fact, the observation that for each attribute measured, the changing pattern between 2 genotypes of each species was generally consistent indicates that the lab scale dehulling and abrading method used in this study is useful and reliable in separating different layers of cereal grains for compositional study.

Conclusion

This study was the first to provide comparative information about lipid and FA distributions within kernels of 5 small grain species (barley, oats, rice, sorghum, and wheat). The results revealed that from outer surface to inner core of seeds, oil content decreased, while C16:0 and C18:0 increased, C18:1 and C18:3 decreased, and C18:2 changed slightly. This new finding points out 2 reasons of improved oxidative stability for pearled kernels: reduced oil content and shifting FAs toward more saturated and less unsaturated composition.

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